Concurrent transcranial direct current stimulation (tDCS) and functional MRI reveals modulatory effects on brain activation during a simple motor task

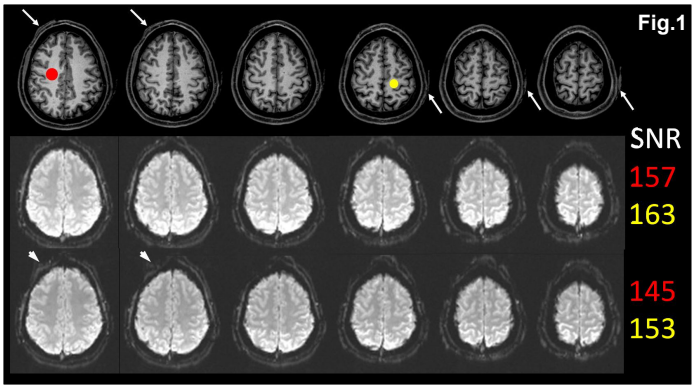
P. Dechent[1], R. Polania[2], C. Schmidt-Samoa[1], W. Paulus[2], and A. Antal[2]

[1]MR-Research in Neurology and Psychiatry, University Göttingen, Göttingen, Germany, [2]Department of Clinical Neurophysiology, University Göttingen, Göttingen, Germany

Introduction: Anodal and cathodal transcranial direct current stimulations (tDCS) have been shown to have facilitatory and inhibitory effects, respectively, on the stimulated cortical networks. Given sufficient stimulation duration the effect of stimulation can outlast the duration of the stimulation for several hours [1]. Combining functional MRI (fMRI) with concurrent tDCS allows for a non-invasive detailed examination of tDCS-induced effects throughout the brain.

In the present study we used concurrent tDCS-fMRI to test whether anodal and cathodal tDCS result in blood oxygenation level dependent (BOLD) fMRI signal changes in a resting condition. Furthermore, we examined the effects of tDCS on the brain network activated by a voluntary finger tapping task.

Methods: ***tDCS.*** Direct current was provided via a pair of MR-compatible square rubber electrodes (7 x 5 cm) connected to a dedicated battery-driven stimulator outside the magnet room (NeuroConn, Ilmenau, Germany). Electrodes were positioned over left primary motor cortex (M1) hand area (identified by transcranial magnetic stimulation; TMS) and above the contralateral right orbita (**Fig.1, arrows in top row**). For cathodal tDCS, the cathode was placed above M1, for anodal tDCS the direction of the electric flux was reversed. In control experiments, anode and cathode were placed over the occipito-temporo-parietal junctions.

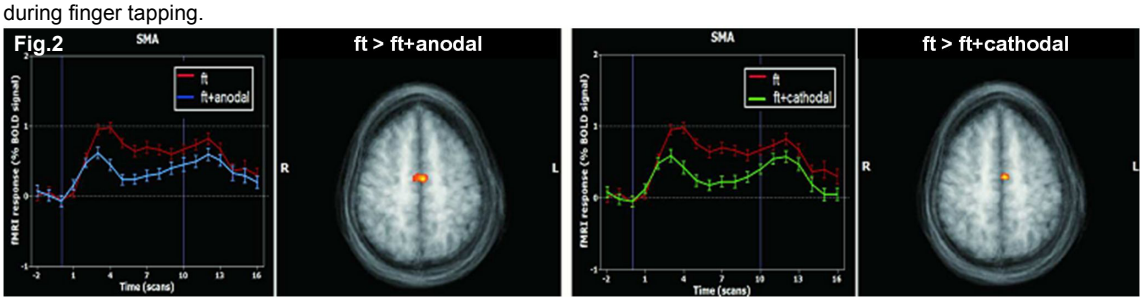


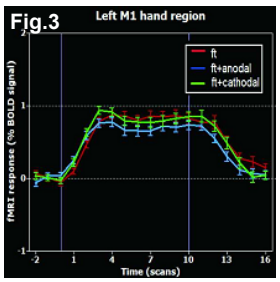
MRI. MRI was performed on 11 healthy, right-handed adults (age 26 ± 4 years) at 3 Tesla (Magnetom TIM Trio, Siemens, Germany) using the standard eight-channel head coil. Initially, an anatomical T1-weighted MR dataset covering the whole head at 1 mm³ isotropic resolution was acquired (3D Turbo FLASH). For BOLD fMRI a T2*-sensitive EPI technique with an in-plane resolution of 2 x 2 mm² was used (TR: 2000 ms, TE: 36 ms, flip angle: 70°, acquisition matrix: 96 x 128, 22 axial sections of 4 mm thickness). The effects of the tDCS-equipment on EPI raw images were assessed in one subject by comparing SNR (mean signal in regions-of-interest (**Fig.1, red/yellow circles**) divided by the standard deviation of background noise) and susceptibility artifacts from measurements with and without tDCS-equipment.

Experimental Protocol and Data Analysis. In a block design alternating task and rest phases (20 s each) were repeated eight times. Five runs were performed with the following conditions during the task-phase: (1) anodal tDCS (*anodal*), (2) cathodal tDCS (*cathodal*), (3) finger tapping of the right index finger (*ft*), (4) finger tapping plus anodal tDCS (*ft+anodal*), and (5) finger tapping plus cathodal tDCS (*ft+cathodal*). tDCS was applied only during the 20 s task-phase at 1 mA intensity (ramp-up/-down over the first/last 2 s). Group analysis and visualization were achieved using BrainVoyager QX (Brain Innovation, The Netherlands). A fixed effects group analysis was performed using the multi-study, multi-subject approach of the general lineal model (p(Bonf) < 0.01).

Results: Introducing the tDCS-equipment into the scanner environment (**Fig.1, bottom row**) did only have very mild negative effects. Compared to the measurement without tDCS-equipment (**Fig.1, middle row**), SNR was hardly reduced (maximum decrease 8 %). Mild susceptibility artifacts were observed under the frontal electrode (**Fig.1, arrowheads**), however, not affecting the underlying brain tissue. The electrode over M1 did not cause any visible artifacts.

Regarding the tDCS experiments, neither anodal nor cathodal tDCS over left M1 induced a detectable BOLD signal change. However, in comparison to a voluntary finger tapping task without stimulation, both anodal and cathodal tDCS during finger tapping resulted in a decrease in the BOLD response in the supplementary motor area (SMA, **Fig.2**). There was no alteration of the BOLD response in M1 during tDCS (**Fig.3**). In control experiments with electrodes placed over the occipito-temporo-parietal junctions, neither cathodal nor anodal stimulation resulted in a significant change of BOLD activation during finger tapping.





Discussion: According to our knowledge, there is only one study published using concurrent fMRI and tDCS [2]. In this study only anodal tDCS was applied over M1 using 4 x 21s stimulation phases (rest-tDCS-tDCS-tDCS-tDCS). No cortical activation was detected in any of the stimulation phases except the fourth tDCS phase. Activation was found under the electrode but also in SMA and right posterior parietal cortex. In contrast, in our study anodal and cathodal tDCS over M1 applied without a motor task did not lead to any detectable activation in any brain area. Applying tDCS during a motor task modulated the BOLD signal changes in SMA, but again not in M1 directly under the electrode.

In summary, we applied both cathodal and anodal tDCS during fMRI for the first time. We conclude that the observation of the BOLD signal attenuation to a large degree fits into a concept of tDCS acting as a modulator. In our study both anodal and cathodal stimulation resulted in an attenuation of the BOLD response in SMA during a motor task well in line with neurophysiological behavior during activation [3]. Although fMRI can be implemented before-after tDCS to measure any enduring changes in brain activity (e.g. [4]), the combination of fMRI and concurrent tDCS may allow a more direct examination of the relation of tDCS-application and neuronal activity. Indeed, it promises a direct visualization of the electrical stimulation-induced changes in brain activity with high spatial resolution and the possibility to chart how tDCS modifies ongoing brain activations.

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